SCIENCE

FRIDAY, JULY 26, 1912

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MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

SIR WILLIAM HERSCHEL[1]

DURING the last twenty years there has been a great revival of statistical investigations as to the distribution and motions of the so-called fixed stars. Kapteyn, of Groningen, is the leader of those who are renewing the attempt to obtain in this way some idea as to the construction of the universe. Earlier astronomers had of course done something in this direction, but the work of William Herschel so far transcends that of all others, that it would be fair to describe him as the originator of this class of investigation. It may be of interest to mention that a complete edition of his works is now in course of publication, under the direction of a joint committee of the Royal and Astronomical Societies.

The interest of Herschel's writings, and the simple charm of his style—written it is to be remembered in a language which was not his from birth—have led me on to read about the man as well as about his scientific work. Throughout his life's work his name is inseparable from that of his sister Caroline, and I hope it may prove of interest to you to hear of what they were as well as of what they did. They were born at Hanover, he in 1738, she in 1750, the children of a bandsman of the Hanoverian Guards. At the age of fifteen Herschel was already a member of the Guards' band. In 1757 the regiment, which had been in England for about a year, served in Germany during the Seven Years' War, and William seems to have suffered from the hardships of the cam-

[1] An address before the Royal Institution of Great Britain, given on April 26, 1912.

paign. His parents, seeing that he had not the strength for a soldier's life, determined to remove him from the regiment. The removal may be described more bluntly as desertion, for we learn that when he had passed the last sentinel at Herrenhausen, he took off his uniform and his luggage was secretly sent after him to Hamburg. At any rate, fortunately for science, he escaped, and in 1757 or 1758 made his way to England.

It would perhaps be impossible to follow him throughout his wanderings, but we know that he was at one time instructor of the band of the Durham Militia, and afterwards that he gained his living as a musician in Leeds, Halifax, Pontefract and Doncaster. In 1764 he even ventured back to Hanover for a short time, and thus saw his favorite sister again.

During her early years Caroline seems to have been practically the household drudge or general servant, and whatever she learned was by stealth or in the scanty intervals snatched from her household duties, for her mother thoroughly disapproved of education for a girl.

When we reflect on the difficulties under which both brother and sister labored, and then consider how much they were able to accomplish, we might be tempted to underrate the value of educational advantages. Concerning education, Bishop Creighton once said in my hearing, "It is surprising how little harm we do notwithstanding all the pains we take." Paraphrasing the remark, although spoiling the epigram, I would say, "It is surprising how little harm the lack of opportunity does to a great genius."

In 1766 William took a position as organist at Bath, then at the height of fashion. The orchestra at the Pump Rooms and at the theatre at Bath was then one of the best in the kingdom, and Elizabeth Linley, daughter of the director of the orchestra, was the prima donna of the concerts. When in 1771 she became engaged to Charles Sheridan, Herschel thought that the expected vacancy would make an opening for his sister at Bath, and suggested that she should join him. And, in fact, after a time such a vacancy did occur, for Elizabeth Linley, after flirting with Charles Sheridan, jilted him and eloped with and married the celebrated Richard Brinsley Sheridan.

Caroline was very anxious to accede to her brother's suggestion, but the rest of the family would not for a time hear of it. At length, however, in 1772, Herschel came to Hanover and carried off his sister with the mother's reluctant consent. Even from boyhood his intense love of astronomy had been manifest, and it is interesting to note that in passing through London on their way from Harwich to Bath, when they went out to see the town, the only sights which attracted their attention were the opticians' shops.

On Mr. Linley's retirement from the orchestra at Bath, Herschel became the director and the leading music-master in the town, and he thus obtained an established position. Although Caroline sang a little in public, her aspiration to become the prima donna of Bath was not fulfilled. But she was kept busy enough at first in the cares of housekeeping, with endless wrangling with a succession of incompetent slaveys, and then she gradually became more and more her brother's astronomical assistant.

In the midst of Herschel's busy musical life he devoted every spare moment to astronomy, and when his negotiations for the purchase of a small reflecting telescope failed—and they were all small in those days—he set to work to make mirrors for himself.

One room in the house was kept tidy for pupils, and the rest of the house, including the bedrooms, was a litter of lathes and polishing apparatus. He made reflecting telescopes not only for his own use, but also for sale, for the purpose of providing funds to enable him to continue his researches. His industry must have been superhuman, for later in his life he records that he had made over 400 mirrors for Newtonian telescopes, besides others of the Gregorian type. These mirrors ranged in diameter from a few inches to 4 feet, in the case of the great 40-foot telescope. I should say that mirrors are not specified by the diameter of the reflecting surface, but by the focal length. Thus, whatever may be the diameter of the reflecting surface, a 20-foot telescope means that the mirror is approximately portion of a sphere of 40 feet in radius, and this will give a focal length of 20 feet. You must, in fact, double the focal length of a telescope to find the radius of the sphere of which it forms a small part.

In order to learn anything of the making of reflectors it is necessary to go to original memoirs[2] on the subject, and even of them there are not many. I feel, therefore, that I shall not be speaking on a topic known to many of the audience if I make a digression on a singularly fascinating art. Mirrors are now made of glass with a reflecting surface of chemically deposited silver; formerly they were made of speculum metal, an alloy of copper and tin. Of whatever substance the mirror is made the process of working it to the required form is much the same. The most complete account of the process of which I know is contained in a paper by Professor G. W. Ritchey in Vol. 34 (1904) of the Smithsonian Contributions to Knowledge. He there gives a full description of the great reflector of the Yerkes Observatory. The process only differs from that employed by Herschel in that he worked by hand, whereas machinery is now required to manipulate the heavy weight of the tools. The Yerkes mirror is formed of a glass disk 5 feet in diameter, and it weighs a ton; the grinding tools are also very heavy.

I must pass over the preliminary operations whereby the rough disk of St. Gobain glass was reduced to a true cylindrical form, smooth on both faces and round at the edge. Nor will I describe the grinding of a shallow depression on one of the faces by means of a leaden tool and coarse emery powder.

It will be well to begin by an account of the manufacture of the tools wherewith the finer grinding and polishing is effected, and then I shall pass on to a short description of the way they are used.

Two blocks of iron are cast with the desired radius of curvature, the one being concave and the other convex. The castings are then turned so that the concavity and convexity fit together as nearly as may be. For the large mirror these blocks are a little over 2 feet 6 inches in diameter, but for small ones they are made of the same diameter as the mirror to be ground. The two are then ground together for a long time with emery powder and water until every part of one surface fits truly to every part of the other. They must then both be portions of a sphere of the same radius, because the sphere is the only surface in which a universal fit is possible. The concave iron is very precious because it furnishes the standard for regrinding the convex grinding tools when they have become worn by use. In order to make a plane mirror, three surfaces are ground

[2] Sir Howard Grubb's lecture at the Royal Institution in 1887 is one of these, Vol. XI., p. 413. Lord Rosse's papers are amongst the most important.

two and two, for if A fits B and C, and B fits C all over each surface they must all be true planes. However, I shall only speak of the figuring of concave mirrors.

The roughly hollowed glass disk is now laid on several layers of Brussels carpet centrally on a massive horizontal turn-table. The convex iron tool just described is suspended by a universal joint from a lever, and it is counterpoised so that only a portion of the weight of the tool will rest on the glass when it is in use. A complicated system of cranks and levers is so arranged that the tool can be driven by machinery to describe loops or curves of any arbitrarily chosen size over the glass, and as these loops are described by the tool the turn-table turns round slowly. In this way every part of the tool is brought into contact with every part of the glass disk in a systematic way. When working near the edge a large part of the tool projects beyond the edge of the glass.

Emery powder and water are supplied in a way I need not describe, and the tool is lowered gently on to the glass. The motive power is then applied, and the grinding is continued for many hours until the preliminary rough depression has been hollowed to nearly the desired shape—namely, that of the standard concave iron.

For finer grinding a change of procedure is now adopted, and very finely powdered emery is used. Another convex tool is formed, by grinding with the standard concavity; the working face of the tool is, however, now cut up into small squares by a criss-cross of narrow and shallow channels. Such channels are found to be necessary in order to secure an even distribution of the emery and water all over the surface. The grooved tool is now used for many hours, and the surface is tested at frequent intervals with a spherometer. The work ceases when it is no longer possible to detect errors of curvature in this way.

The next stage is polishing. The thickness of the layer of glass worn off in polishing is to be estimated in ten-thousandths of an inch, and can scarcely be detected even with the finest spherometer. For polishing the iron tool is discarded and the work is carried on by hand. As lightness is essential, the tool is built up by a stiff lattice-work of wood with a continuous wooden working face. It is obvious that however carefully the face may be turned it can not be made sufficiently true, and the requisite accuracy is obtained by means of the plastic properties of rosin or pitch. A number of squares of rosin about a quarter of an inch thick and an inch square are made, and these are glued in rows on the convex face of the wooden tool, with a narrow space intervening between each rosin square and its neighbors. The tool is then warmed slightly so as to soften the rosin a little, and it is then pressed lightly on to the glass disk. By means of this "warm-pressing" a nearly perfect fit is attained.

Each of the rosin squares is then painted with hot melted wax. This is done because wax is harder than rosin and affords a better working face. Finally, when the tool is quite cold, the surface of the glass is painted all over with very finely powdered rouge and water, and the tool is placed gently on the glass with some additional weight resting on it. It is left thus for several hours, but is moved slightly every ten minutes to ensure an even distribution of the rouge and water. By means of this "cold-pressing" a perfect fit is secured of the wax-coated rosin squares with the glass face. Cold-pressing has to be repeated every day before the work begins.

The polishing is now carried on in much the same way as the grinding, but by hand instead of by machine power. The turn-table can be made to tilt so as to bring the

glass to stand vertically, instead of horizontally, and the disk is frequently tilted up so as to submit the surface to optical tests. These latter tests are far more searching than those with a spherometer, and enable the observer to detect an error in the radius of curvature of portion of the reflector of a hundredth of an inch. To correct such an error it will be necessary to remove a layer of glass of $\frac{1}{500000}$ths of an inch!

The most refined optical test is by the observation of the image of a brilliant light issuing from a pin-hole close to the intended center of the spherical surface. The observer examines the image of the pin-hole with a microscopic eye-piece placed as close as possible to the pin-hole. He then causes a straight-edge close in front of the eye-piece to move slowly across the reflected beam of light, either from left to right or from right to left, so as to eclipse the light. Previously to the eclipse the whole of the glass seems to be a uniform blaze of light, and if the curvature is perfect the light which enters the observer's eye comes from all parts of the disk, and the surface is seen to darken equably all over. But if the surface is imperfect the light from some part is eclipsed sooner than that from others, and the disk seems to possess considerable hills and valleys illuminated, as it were, by a setting sun.

The interpretation of these apparent hills and valleys shows where further local polishing with a small tool is requisite. Sir Howard Grubb says that if he suspects a hollow, he holds his hand near the surface for a minute or two; if a hill is suspected, he washes the region with an evaporating wash. The warmth in the one case and the cooling in the other tend to rectify, and indeed over-rectify, the errors.

When success is finally attained, after all we have only a spherical surface, and it becomes necessary to obtain a parabolic form. This last stage is done by further tests of the kind described, with a diaphragm placed over the mirror which only permits the observer to see the light reflected from chosen zones of the mirror. The time at my disposal will not allow me to describe this in further detail, or to tell you how there is always found to be one definite diameter of the glass along which its weight must be supported. I must pass by, too, the system of counterpoised levels used for supporting the back of the glass, and the method by which silver is chemically deposited on its surface. Meager although this sketch has been, it will have served to show you how beautiful are the processes employed, and I would ask you to realize that at first Herschel was a mere amateur, and had to discover everything for himself.

As I have said, Hershel had to do all his polishing by hand, and he found when once the final stage had begun, it was necessary that it should never stop even for a moment. Caroline relates how she was kept busy in attending on her brother when polishing:

> Since by way of keeping him alive I was constantly obliged to feed him by putting the victuals by bits into his mouth. This was once the case, when in order to finish a 7-ft. mirror, he had not taken his hand from it for sixteen hours together.

The making of the mirror is, however, but a small part of the difficulty of making a telescope, for it involves high engineering skill to provide a solid stand, an observing platform, the graduated circles in right ascension and declination for setting the telescope and the clock, whereby it is made to follow the stars in their daily motion. The great size of Herschel's mirrors and the weight of the long tube introduced mechanical difficulties which were at that time entirely new.

A dozen years after his establishment at Bath, Herschel began to be well known in the world of science, and many of the most illustrious astronomers came to see him. In 1781 he was elected to the Royal Society, and in the same year he discovered the planet Uranus, and called it by the now almost forgotten name of Georgium Sidus, in honor of George III. The magnitude of the discovery may be estimated by the fact that only the five principal planets, familiar to all men for centuries, were then known; and the asteroids or minor planets had not yet been discovered by Herschel himself. His fame from this and his other discoveries led to a command from the King to take his 7-foot telescope to Windsor, and there he was requested to act as celestial showman to the King, the Queen, and the Princess. The expedition put him to much expense, and he was kept hanging about Windsor for months, but at length the King offered him the post of private royal astronomer, with the modest salary of £200 a year.

Herschel's friend, Sir William Watson, said that never had a monarch bought honor so cheap, and Caroline pours scorn on the king's meanness; but I think this was hardly fair. It must have been well known that Herschel had deserted from the Hanoverian Guards, and while the King might consent to forget this, it was a strong measure to take the deserter into his service. At a later date, moreover, when the King was informed by Sir Joseph Banks of Herschel's financial difficulties, he granted him £2,000, afterwards increased to £4,000, for the construction of the great 40-ft. telescope, with the condition that he should retain it for his own use. To this was added a further £200 a year for maintenance, and a pension of £50 a year to Caroline Herschel. And besides he was allowed to make specula for sale, and half the observatories of Europe were so furnished by him at prices which were then thought considerable.

At any rate Herschel jumped at the offer, which, by relieving him from his musical slavery, allowed him to follow the wish of his life. The Herschels then came to the neighborhood of Windsor, and after several removals they finally settled at Slough. The change was delightful for him, since he now had space for his telescopes and workshops, but the difficulties of housekeeping in a rambling and dilapidated house rendered the change somewhat less agreeable to his sister.

The closeness to Windsor was perhaps a necessity of the case, but it had its disadvantages, since he was frequently summoned to take his telescope to Windsor, or large parties from the castle would visit him at his house in order to see the wonders of the heavens. When his time had been wasted in this way he would make up for the loss by redoubled labor.

The fury, as I may call it, with which they worked may be gathered from Caroline's journal, and the work was not free from danger, because in his eagerness Herschel would not always delay his observations until the telescope was properly fixed. To stand in the dark on a platform without a railing, when your attention is distracted from your position, can not be very safe, and they both met with a good many accidents which might easily have proved fatal.

The incessant work, together with the interruptions by the visitors from the castle, began at length to tell on Herschel's health. His sister notes that on the 14th of October, 1806, after working all day, he was out from sunset till past midnight surrounded by fifty or sixty persons, without food or proper clothing, and that he never

seemed to recover completely from this great strain on his strength.

But I have passed by an event of importance in the lives of both brother and sister, for in 1783 he married Mrs. Pitt, a lady of singularly amiable and gentle character. To the sister, however, the marriage was a great blow, for, although she continued to be his secretary and assistant, she moved into neighboring lodgings, and was no longer so closely associated with him as theretofore. Mrs. John Herschel writes: "It is not to be supposed that a nature so strong and a heart so affectionate should accept the new state of things without much and bitter suffering," and tradition confirms this belief. All her notes and memoranda relating to a period of fifteen years from the time of the marriage were destroyed by her when, as we may presume, her calmer judgment showed her that the record of her heart-burning would be painful to the surviving members of the family. At any rate, she was on affectionate terms with her sister-in-law throughout all the later years of her life, and the brilliant career of her nephew, the celebrated Sir John Herschel, and correspondence with him, afforded the leading interest of her old age.

Although Herschel lived until 1822, and accomplished an enormous amount of work up to the end of his life, yet his health seems to have declined from about the time I have noted. On his death Caroline felt that her life, too, was practically ended and she returned to Hanover. Ever afterwards she used to cry, "Why did I leave happy England?" and it is incomprehensible that she should not have returned to the place where all her real interests lay.

Although she felt the death of her brother as practically the end of her life, she was always full of jokes and fun. In a letter to her nephew, she told him that her father used to punish her, a grown woman, by depriving her of her pudding if she did not guess rightly the angle of the piece she had helped herself to. Dr. Groskopf writes of her when she was eighty-nine years of age:

> Well! what do you say of such a person being able to put her foot behind her back and scratch her ear with it, in imitation of a dog, when she was in one of her merry moods?

She only died in 1847, having very nearly completed her ninety-eighth year.

Herschel himself must have been a man of singular charm, as is testified to by Dr. Burney and his daughter Mme. d'Arblay. That he possessed an incredible amount of patience is proved by the fact of his submitting to the reading aloud of the whole of a portentous, and fortunately unpublished, poem in many cantos by Dr. Burney, entitled "A Poetical History of Astronomy." It appears that Herschel had had an interview with Napoleon in Paris in 1802, and the poet Campbell asked him whether he had been struck by Napoleon's knowledge. Said Herschel:

> No, the First Consul surprised me by his versatility, but in science he seemed to know little more than any well-educated gentleman, and of astronomy much less, for example, than our king. His general air was something like affecting to know more than he did know.

He was struck, too, by Napoleon's hypocrisy in observing "how all these glorious views gave proofs of Almighty Wisdom."

And now having endeavored to show what kind of people Caroline and her brother were, I must turn to what they did. Herschel's discoveries were so numerous that I am compelled to make a selection. I shall therefore only attempt to sketch his endeavor to understand the general construction of the stellar universe, and to speak of his work on double stars.

The only general test of the relative nearness or farness of the stars is their brightness, because the faint stars must, on the average, be more distant than the bright ones. Herschel then proposed to penetrate into space by means of a celestial census of the distribution and of the brightness of the stars. With this object he carried out four complete reviews of the heavens, as far as they may be seen from our latitude, passing successively to the fainter and fainter objects by means of the increased size of his telescope.

He divided the heavens into sweeps 2° 15′ of breadth in declination, and each zone was examined throughout by the process which he called star-gauging. His census was made with the 20-ft. reflector, with which instrument the field of view was about one quarter of the size of the full moon. It needs over 300,000 of such fields of view to cover the whole of the hemisphere of space, and Herschel surveyed the whole northern hemisphere, and as much of the southern one as he could.

Von Magellan in a letter to Bode describes the method of observation as follows:

> He has his 20-ft. Newtonian telescope in the open air. . . . It is moved by an assistant who stands below it . . . near the instrument is a clock . . . in the room near it sits Herschel's sister, and she has Flamsteed's Atlas open before her. As he gives her the word, she writes down the declination and right ascension. . . . In this way Herschel examines the whole sky . . . he is sure that after four or five years (from 1788) he will have passed in review every object above our horizon. . . . Each sweep covers 2° 15′ in declination, and he lets each star pass at least three times through the field of the telescope, so that it is impossible that anything can escape him. . . . Herschel observes the whole night through . . . for some years he has observed . . . every hour when the weather is clear, and this always in the open air.

Herschel points out that by this survey he was not only looking into the most distant space, but also into the remotest past, for the light of many of the stars must have started on its journey towards us thousands or even millions of years ago. The celestial museum therefore exhibits to us the remotest past alongside with the present, and we have in this way the means of reconstructing to some extent the processes of evolution in the heavens. In photography the modern astronomer possesses an enormous advantage, but Herschel laid the foundation of this branch of astronomy without it.

The most conspicuous and the most wonderful object in the heavens is the Milky Way. It runs all round the skies in a great band, with a conspicuous rent in it forming a streamer which runs through many degrees. To the naked eye it shines with a milky light, but Herschel was able to show that it consists of countless stars in which there lie embedded many fleecy nebulæ. There is good reason to believe that the Milky Way on the whole consists of stars which are younger than those in the other parts of space, for the stars in it are whiter and hotter, and the nebulæ are mostly fleecy clouds. On the other hand, the spiral and planetary nebulæ are more frequent away from the Milky Way, and these are presumably older than the cloudy and flocculent nebulæ. The shape of the Milky Way seems to resemble a huge millstone or disk of stars, and since it forms a complete circuit in the heavens the sun must lie somewhere towards its middle. It is probable that we look much further out into space along this tract than elsewhere, although it happens that by far the nearest of all the stars—namely, α Centauri—lies in the line of the Milky Way.

This great congregation of stars is far from uniform in density, for there are places in it where there are but few stars or none at all. Caroline Herschel, writing

to Sir John Herschel at the Cape of Good Hope, in 1833, mentions that her brother, when examining the constellation of the Scorpion (which lies at best low down on our horizon), had exclaimed, "after a long, awful silence, 'Hier ist wahrhaftig ein Loch im Himmel.'" And her nephew, as he said, rummaged Scorpio with the telescope and found many blank spaces without the smallest star.

It will explain some of the deductions which Herschel drew from his star-gauges, and will at the same time furnish a good example of his style, if I read a passage from a paper of his written in 1789.[3] He points out that the sun is merely a star, and, referring to the stars, he continues thus:

These suns, every one of which is probably of as much consequence to a system of planets, satellites and comets, as our own sun, are now to be considered in their turn, as the minute parts of a proportionally greater whole. I need not repeat that by my analysis it appears that the heavens consist of regions where suns are gathered into separate systems, and that the catalogues I have given comprehend a list of such systems; but may we not hope that our knowledge will not stop short at the bare enumeration of phenomena capable of giving us so much instruction? Why should we be less inquisitive than the natural philosopher, who sometimes, even from an inconsiderable number of specimens of a plant, or an animal, is enabled to present us with the history of its rise, progress and decay? Let us then compare together, and class some of these numerous sidereal groups, that we may trace the operations of natural causes so far as we can perceive their agency. The most simple form, in which we can view a sidereal system, is that of being globular. This also, very favorably to our design, is that which has presented itself most frequently, and of which I have given the greatest collection.

But, first of all, it will be necessary to explain what is our idea of a cluster of stars, and by what means we have obtained it. For an instance I shall take the phenomenon which presents itself in many clusters. It is that of a number of lucid spots, of equal luster, scattered over a circular space, in such a manner as to appear gradually more compressed towards the middle, and which compression, in the clusters to which I allude, is generally carried so far, as, by imperceptible degrees, to end in a luminous center of an irresolvable blaze of light. To solve this appearance it may be conjectured that stars of any given very unequal magnitudes may easily be so arranged, in scattered, much extended, irregular rows, as to produce the above described picture; or, that stars, scattered about almost promiscuously within the frustum of a given cone, may be assigned of such properly diversified magnitudes as also to form the same picture. But who, that is acquainted with the doctrine of chances, can seriously maintain such improbable conjectures?

Later in the same paper he continues:

Since then almost all the nebulæ and clusters of stars I have seen, the number of which is not less than three and twenty hundred, are more condensed and brighter in the middle; and since, from every form, it is now equally apparent that the central accumulation or brightness must be the result of central powers, we may venture to affirm that this theory is no longer an unfounded hypothesis, but is fully established on grounds which can not be overturned.

Let us endeavor to make some use of this important view of the constructing cause, which can thus model sidereal systems. Perhaps, by placing before us the very extensive and varied collection of clusters and nebulæ furnished by my catalogues, we may be able to trace the progress of its operation in the great laboratory of the universe.

If these clusters and nebulæ were all of the same shape, and had the same gradual condensation, we should make but little progress in this enquiry; but as we find so great a variety in their appearances, we shall be much sooner at a loss how to account for such various phenomena, than be in want of materials upon which to exercise our inquisitive endeavors.

. . . .

Let us, then, continue to turn our view to the power which is molding the different assortments of stars into spherical clusters. Any force, that acts uninterruptedly, must produce effects proportional to the time of its action. Now, as it has been shown that the spherical figure of a cluster of stars is owing to central powers, it follows that those clusters which, *ceteris paribus*, are the most

[3] *Phil. Trans.*, Vol. LXXIX., p. 212.

complete in this figure, must have been the longest exposed to the action of these causes. This will admit of various points of view. Suppose, for instance, that 5,000 stars had been once in a certain scattered situation, and that other 5,000 equal stars had been in the same situation, then that of the two clusters which had been longest exposed to the action of the modelling power, we suppose would be most condensed, and more advanced to the maturity of its figure. An obvious consequence that may be drawn from this consideration is that we are enabled to judge of the relative age, maturity or climax of a sidereal system, from the disposition of its component parts; and, making the degrees of brightness in nebulæ stand for the different accumulation of stars in clusters, the same conclusions will extend equally to them all. But we are not to conclude from what has been said that every spherical cluster is of an equal standing in regard to absolute duration, since one that is composed of a thousand stars only must certainly arrive to the perfection of its form sooner than another which takes in a range of a million. Youth and age are comparative expressions; and an oak of a certain age may be called very young, while a contemporary shrub is already on the verge of its decay. The method of judging with some assurance of the condition of any sidereal system may perhaps not improperly be drawn from the standard laid down earlier; so that, for instance, a cluster or nebula which is very gradually more compressed and bright towards the middle may be in the perfection of its growth, when another which approaches to the condition pointed out by a more equal compression, such as the nebulæ I have called *Planetary* seem to present us with, may be looked upon as very aged, and drawing on towards a period of change, or dissolution. This has been before surmised, when in a former paper I considered the uncommon degree of compression that must prevail in a nebula to give it a planetary aspect; but the argument which is now drawn from the powers that have collected the formerly scattered stars to the form we find they have assumed, must greatly corroborate that sentiment.

This method of viewing the heavens seems to throw them into a new kind of light. They now are seen to resemble a luxuriant garden, which contains the greatest variety of productions, in different flourishing beds; and one advantage we may at least reap from it is, that we can, as it were, extend the range of our experience to an immense duration. For, to continue the simile I have borrowed from the vegetable kingdom, is it not almost the same thing, whether we live successively to witness the germination, blooming, foliage, fecundity, fading, withering and corruption of a plant, or whether a vast number of specimens, selected from every stage through which the plant passes in the course of its existence, be brought at once to our view?

I now turn to another line of discovery of which I can not show any pictures, but which, to me at any rate, is more interesting. Until 1838—that is to say, until sixteen years after Herschel's death—no one had succeeded in determining the distance of a single fixed star, but in that year Henderson and Bessel almost simultaneously attained success in the cases of the two stars α Centauri and 61 Cygni. The attempts at this measurement had already been numerous, and Herschel amongst others had failed, but his failure was a glorious one, for he made incidentally a discovery of another kind and of at least equal interest.

The earth moves around the sun at a distance of 93 million miles, so that in six months we shift our position by 186 million miles. If, then, there are two stars of which one is relatively near to and the other far from the sun, but so situated as to appear to us very close together, the near one ought to shift its position relatively to the distant one in the course of each six months. The amount of this change of position, called by astronomers annual parallax, should furnish the distance of the nearer of the pair, provided that the other is very far off. This idea is as old as the time of Galileo, but no one had been able to make successful use of it.

As I have already said, the only general test of the distance of a star is its brightness, and therefore Herschel chose pairs of stars of very different brilliancy. He thought, at least at first, that it was mere chance which brought the stars so near to

one another, and there are undoubtedly such pairs now known as "optically double stars." But Herschel's mode of attack was bound to fail if the seemingly neighboring stars were really so, and were linked together by their mutual gravitation. Already as early as 1707 Michel had suggested the existence of such true double stars, but it was Herschel who proved their existence. His first catalogues of double stars, published in 1782, contained 203 cases of such doublets, and he already suspected a community in their motions explicable only by their real association; but by 1802 he had become certain. In many cases the two components of a binary pair were found to be moving in nearly the same direction and at the same speed, but superposed on this motion of the system as a whole there was an orbital motion of one star round the other. Herschel even lived long enough to see some of his pairs of stars perform half a revolution about one another.

After his death Savary took the matter one stage further, and showed that the revolution was governed by the laws of gravity, and thereby confirmed the truth of Herschel's belief. Thus the failure to measure the distance of stars led to the proof that gravity reigns amongst the stars as in the solar system.

Arago thought that of all Herschel's discoveries this was the one that had the greatest future, and his prophecy has proved singularly correct. Every year adds to the number of double stars, whose orbits are now accurately determinable. These systems are found to be very unlike our own solar system, for the component stars are, in many cases, far larger than the sun and revolve about one another in periods which, in various cases, may be either many years or only a few hours.

The spectroscope has, moreover, added enormously to our knowledge, for the speed of approach or recession of a star from the sun can now be determined as so many kilometers per second. Thus that component of the motion of a star which was concealed from Herschel is now known with the greater certainty. Moreover, being ignorant of the distance of the stars, he could only express the transverse component of motion in seconds of arc.

A wonderful corollary also results from the use of the spectroscope, namely, the existence of many stars known as "spectroscopic binaries." As seen even with the most powerful telescope such a star is a single point of light, but if the spectral lines are duplicated we know that the source of light is double, and that one component is approaching us and the other receding from us. In this way the orbits and relative masses of these visually inseparable stars are determinable. The number of known double stars, including both visual and spectroscopic ones, is already large, and Campbell, of Lick Observatory, has expressed his opinion that one star in six is double. Some of them revolve so near to one another and in such a plane that they partially eclipse one another as they revolve, and thus produce a winking light like that of a lighthouse. It would seem that we can now even tell something of the shapes of a pair of stars visually inseparable from one another. But I must not go further into this subject, and will only repeat Arago's saying, that this discovery of Herschel's has "le plus d'avenir."

It is a figure of speech to refer to the stars as fixed, for a large number of them possess a measurable amount of "proper motion" relatively to their neighbors. The existence of double stars was discovered by the observation of their movements, and thus the study of proper motions is linked

to the subject of which I have just been speaking. Some few proper motions had been observed by earlier astronomers, but when Herschel took up the subject proper motion had not been accurately measured in any case.

If a man is walking through a wood the trees in front of him seem to be opening out before him, whilst those behind seem to be closing together. In the same way if our sun is moving relatively to the center of gravity of all the stars, the stars must on the average seem to move away from the point towards which the sun is travelling, whilst they must close in towards its antipodes. These two points are called the apex and antapex of the sun's path.

Now Herschel concluded that there was something systematic in the proper motions of the stars, and that there was a point in the constellation of Hercules from which the stars were on an average receding, and that similarly they were closing in towards the antipodal point. The first of these is the sun's apex and the second the antapex. These conclusions were drawn from the motions of comparatively few stars, but the result has been confirmed subsequently from a large number. Moreover, we have now learned by means of the spectroscope that we are travelling towards Hercules at the rate of about sixteen miles a second.

During these last few years this grand discovery of Herschel's has gained a great extension at the hands of Kapteyn and of many others, and it has been proved that other systematic motions of the stars are discoverable. The time at my disposal will not permit me to pursue this subject further, but I may say that it now appears that if we could view the universe from the center of gravity of the stars of the Milky Way, we should see a current of stars coming from a definite direction of space and penetrating our system.

What a vista of discoveries do these ideas open up to the astronomer! Some centuries hence the sun's apex may have shifted, and we may perhaps learn that the solar system is describing the arc of some colossal orbit. The drift or current of stars may also have begun to change its direction, and our descendants may have begun to make guesses as to its future course and as to its meaning. But whatever developments the future may have in store, we should never forget that the foundation of these grand conceptions of the universe was laid by Herschel. Holden ends his "Life of Herschel" with words which may also serve as a fitting end to my lecture:

> As a practical astronomer he remains without an equal. In profound philosophy he has few superiors. By a kindly chance he can be claimed as the citizen of no one country. In very truth his is one of the few names which belong to all the world.

GEORGE H. DARWIN

PAUL CASPAR FREER. AN APPRECIATION

IT is only a little over a decade since America broke out of her chrysalis and took flight into the large world beyond the range of her time-honored coast lights and began to shake off a little of her provincialism. At her farthest outpost she was fortunate in having sent out many able men. Among those was Paul Caspar Freer, who for ten years has been the director of the Bureau of Science of the government of the Philippine Islands. He went there at a time when the kings and captains had not yet departed and before the shouting had entirely died away. His work was not to run down *ladrones* nor to lend a voice to the tumult incident to a period of reconstruction. He set to work, with little funds and no sympathy, save from a very few, to organize what has become to-day the leading scientific organization in the orient. The writer, who is proud of having served under Dr. Freer for six years, knows what he went through, in that time; of the bitter opposition